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Nonlinear Analysis of Fully Coupled Integrated Spar-Mooring Line System

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ABSTRACT

Oil and gas exploration have moved from shallow water to much deeper water far off the continental shelf. Spar platforms under deep water conditions are found to be the most economical and efficient type of offshore platform. The number of operational Spar platforms such as SB-1, Shell's ESSCO, Brent Spar, Oryx Neptune Spar, Chevron Genesis Spar and Exxon's Diana Spar in the Gulf of Mexico and North Sea prove the effectiveness and success of such platforms in deepwater conditions. For platforms in deeper waters, mooring lines generally contribute significant inertia and damping due to their longer lengths, larger sizes, and heavier weights. Accurate motion analysis of platforms in deep waters requires that these damping values be included. The most common approach for solving the dynamics of Spar platform is to employ a decoupled quasi-static method, which ignores all or part of the interaction effects between the platform and mooring lines. Coupled analysis, which includes the mooring lines and platform in a single model, is the only way to capture the damping from mooring lines in a consistent manner. The present coupling is capable in matching the forces, displacement, velocities and acceleration at the fairlead position along with all possible significant non-linearities. The output from such analyses will be platform motions as well as a detailed mooring line response. The computational efforts required for coupled system analysis considering a complete model including all mooring lines are substantial and should therefore mainly be considered as a tool for final verification purposes. In actual field problems hydrodynamic loads due to wave and currents act simultaneously on Spar platform and mooring lines. In finite element model, the entire structure acts as a continuum. This model can handle all non-linearities, loading and boundary conditions. The commercial finite element code ABAQUS/ AQUA is found to be suitable for the present study. The selected configuration of the offshore Spar platform is analysed under the regular wave loading and its structural response behavior in steady state is studied. The response of Spar-mooring system is obtained after 1 and 3 hours of storm. The result shows the effect of mooring line damping due to fully coupled analysis of Spar-mooring system.

KEY WORDS: Floating structures; Spar platform; Fully coupled; Nonlinear analysis; Hydrodynamic loads; Moring line damping; Deep water exploration.

INTRODUCTION

Depletion of reserves at shallow water depths has seen the oil and gas industry move towards floating rather than fixed offshore structures in order to facilitate the extraction of hydrocarbons. Exploration and development of offshore oil and gas in shallow and intermediate water depths has traditionally been carried out using the conventional jacket type fixed platforms. As the water depth increases fixed platforms become expensive and uneconomical. The emphasis then shifts to compliant/floating production systems. Spar platform is such a compliant floating structure used for deep water applications of drilling, production, processing, storage and off-loading of ocean deposits. Numerous studies have recently been performed in order to assess the effect of the coupling on different offshore floating production systems/ Spar buoy (Ran and Kim, 1996; Ran et al., 1996; Ran and Kim, 1997; Omberg and Larsen, 1998; Chen et al., 1999; Gupta et al., 2000; Cobly et al., 2000; Ma et al., 2000; Chen et al., 2001; Kim et al., 2001a, Kim et al., 2001b, Kim et al., 2001c, Kim et al., 2005; Chen et al., 2006). Ma et al. (2000) have conducted parametric studies on Spar and TLP for different depths up to ultra deep water. Paulling and Webster (1986) established a consistent, nonlinear procedure for the prediction of the large-amplitude coupled motions, which result from the action of wind, waves and currents on the platform and risers. Chen et al. (1999) presented the response of a spar constrained by slack mooring lines to steep ocean waves by two different schemes: a quasi-static approach (SMACOS), and a coupled dynamic approach (COUPLE) to reveal the coupling effects between a spar and its mooring system. In coupled dynamic approach, dynamics of the mooring system are calculated using a numerical program, known as CABLE3D. Ran et al. (1999) studied coupled dynamic analysis of a moored spar in random waves and currents (time-domain versus frequency- domain analysis). Anam et al. (2003) studied time domain and frequency domain analysis of Spar platforms. Tahar and Kim (2008) developed numerical tool for coupled analysis of deepwater floating platform with polyester mooring lines. Low and Langley (2008) presented a hybrid time/frequency domain approach for coupled analysis of vessel/mooring/riser. The vessel was modeled as a rigid body with six degrees-of-freedom, and the lines were discretized as lumped masses connected by linear extensional and rotational springs. The method was found to be in good agreement with fully coupled time domain analysis, when used for relatively shallow water depths. Low (2008) used the same hybrid method to predict the extreme responses of coupled floating structure. Yang and Kim (2010) carried out coupled analysis of hull-tendon-riser for a TLP. The mooring line/riser/tendon system was modeled as elastic rod. It was connected to the hull by linear and rotational springs. The equilibrium equations of hull and mooring line/risers/ tendon system were solved simultaneously. Fan et al. (2008) studied the effect of coupling for cell-truss Spar platform. The Spar mooring/riser was modeled by three methods namely quasi-static coupled, semi-coupled and coupled. The results from frequency-domain and time domain analyses were compared with experimental data.